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Moment Resistant Frames vs. Braced Frames -Steel Consumption Assessment and Structural Analysis Parameters

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Abstract

Selection of an appropriate structural system in steel structures is one of the factors affecting the weight of consumed steel and consequently, the economics of the project. In this paper, buildings with similar plans in 4, 8, 12 and 16 stories were modeled with different structural systems and factors such as the effect of regulation control for steel structure weight and maximum roof displacement, structure frame weight and values of base shear are explored. As a result of increase in expenditures corresponding to building of steel structures, presenting an optimal and appropriate structural plan resulting in maintenance of safety and reduction of consumed steel contributes to project cost reduction. In this paper, moment resistant frames vs. braced frames -steel consumption and structural analysis parameters were evaluated. In other words, it is attempted to evaluate and compare the weight of consumed steel and important structural parameters of the building in two systems; braced frames and moment frames. For this purpose, a building with 27.8×20.6 m cross section and 4, 8, 12 and 16 stories is modeled and studied. Results reveal that for buildings having up to 8 stories, braced frames are preferred and as height increases, utilization of moment frames leads to more optimized weight of consumed steel.

Keywords**:** Structural system; Moment resistant; Steel structure; Braced frame.

1. Introduction

Studying the behavior of building structures as subjected to severe earthquake ground motions reveals that these types of structures can exhibit enough strength, due to the nonlinear behavior of materials and possibility of the sufficient deformations of the structures. These structures absorb the applied energy and will dissipate it via tolerating the great displacements in nonlinear seismic behavior [6-9].

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Today, one of the indicators which affect the quality of construction is final costs and economic justification of the plan. Consequently, one of the most important concerns and criteria of the design of buildings is to reduce weight of structure and hence, making the plan more economical. In steel structures with the residence utility, weight of consumed steel is an appropriate basis for decision of investors and constructors [4-5]. To achieve this goal, it is attempted to minimize the cross section of members as much as possible and at the same time, weight of consumed steel in steel structures is affected by structural systems. Therefore, selection of a suitable structural system is one of the most important and effective decisions in the process of design for reducing economic costs of the project. Structural systems which are being mainly used today are moment frames and braced frames. In comparison with braced frames, moment frames have more deformation capacity and less stiffness [1-3]. Due to many uncertainties associated with the site-specific excitation as well as uncertainties in the parameters of analytical models, in many cases, the effort associated with detailed modeling and analysis may not be justified and feasible [10-12]. Structural frames with infill panels typically provide an efficient method for bracing buildings [13]. In present research, we assess moment resistant frames vs. braced frames - steel consumption and compare two structural systems with 4, 8, 12 and 16 stories. Moreover, effect of combination of concentrated load as well as control of roof drift on structural weight is evaluated. Results reveal that using braced frames in buildings with up to 8 stories is more economic compared to moment frames.

2. Modeling

In this work, to compare lateral resistance systems, a building is modeled and designed with 20.6×27.8m plan, 4, 8, 12 and 16 stories and residence utility. Plan of the building can be seen in Fig. 1. According to Iranian Building Regulation 2800, this building is regular in plan as well as height. Roof of the building is composite and height of each floor is assumed to be 3.5m. In this building, moment frame system with moderate deformability and converging crossed braced frame system are evaluated and compared.

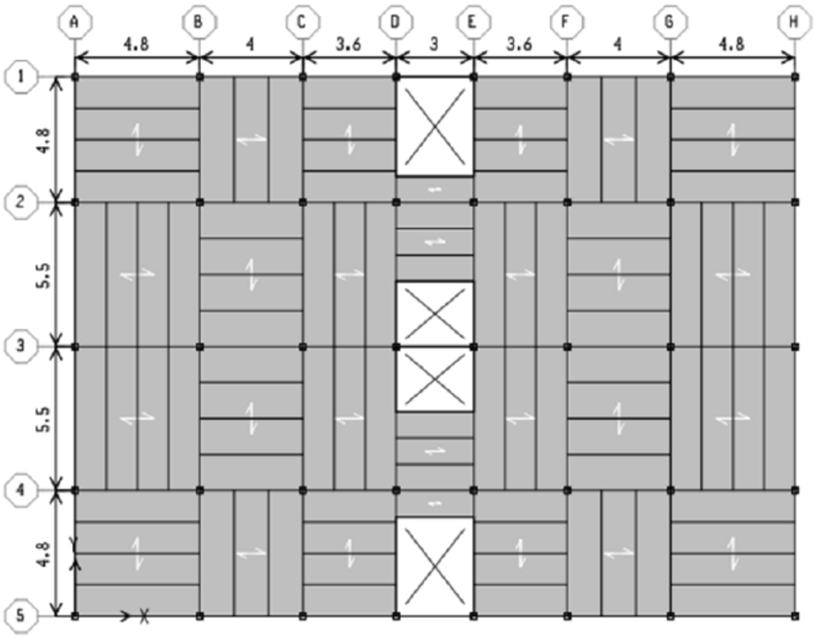

Figure 1: Plan of the studied building

Gravity loads are calculated and applied in accordance with 6^{th} issue of Iranian National Building Regulations. Furthermore, for lateral loading of the building, Iranian Standard 2800 is used. Utility of the building is residence, soil of the building is of type 2 and location of the building is Tehran city with very high seismic hazard (A=0.35).

To analyze and design, ETABS V. 9.7.1 and for seismic analysis, spectral analysis in accordance with Standard 2800 is utilized. Design of steel framework and composite roofs is performed in accordance with regulation AISC-ASD89. This regulation has the most compliance with 9^{th} issue of Iranian National Building Regulations and in this regard, it is the most appropriate regulation for design of the structure. In moment frame system, for main beams, I-shaped beam and plate is used, for secondary beams, IPE sections and for columns, BOX sections are used. Moreover, in braced frame system, for all beams IPE section, for columns, BOX section and for brace, IPE and 2IPE sections are used.

3. Results and discussion

In this section, explanation and interpretation of results corresponding to the effect of control of regulations on the weight of consumed steel as well as roof displacement are presented first and then, weight of consumed steel, values of base shear and roof displacement for two systems; braced frame and moment frame are evaluated and compared. According to 10^{th} issue of Iranian National Building Regulations, columns must be designed for axial load resulted from combination of concentrated load. In addition, 6^{th} issue of National Building Regulations limited the value of roof drift to a certain value. In what follows, effect of control of the regulation on weight of consumed steel and roof displacement is explained. Since loads resulted from earthquake in braced frames is transferred through braces to columns, in this frame, axial load resulted from combination of concentrated loads becomes critical and column cross section must be reinforced. However, in moment frames, combination of concentrated load has no significant effect on axial load of columns, and the reason of which is that a bending structure resists against lateral loads. Therefore, combination of concentrated load rarely leads to reinforcement of columns in moment frames. As height of building increases, floors drift exceeds the allowable value and to control it, stiffness of the structure must be improved. Hence, stronger sections must be used and this issue leads to increase in weight of consumed steel. In the process of building design, control of floors drift and optimizing the structural plan, change of the sections with more load bearing capacities was put under scrutiny. For this purpose, work – energy diagrams of ETABS are used. Consequently, in some columns and braces of braced frame as well as some beams of moment frame, cross section change occurred.

Values of framework weight and maximum roof displacement in two previous cases and after control of regulations are summarized in table 1. Interpretation of results can be observed in Figure 2.

According to results presented in table 1 and figure 2, it can be postulated that the control of regulation contributes to the weight of consumed steel. This effect is more pronounced for braced frame with more stories so that in braces frames with 12 and 16 stories, weight of consumed steel increased as 42% and 35%, respectively. In this case, according to heavy weight of structure framework, such increase imposes significant costs to the project from economical point of view.

Table 1: Results of the effect of control regulation on weight of consumed steel and maximum roof displacement

Lateral load bearing system	Number of stories	Before regulation control		After regulation control	
		Weight of steel (ton)	Maximum displacement (cm)	Weight of steel (ton)	Maximum displacement (cm)
Braced frame	4	93.7	2.6	96.8	2.6
Braced frame	8	245.7	9.0	267.0	7.8
Braced frame	12	451.9	19.3	642.1	11.8
Braced frame	16	708.3	29.1	957.9	17.2
Moment frame	4	104.9	5.7	108.0	5.0
Moment frame	8	300.9	11.7	312.3	10.3
Moment frame	12	481.0	17.3	493.7	15.6
Moment frame	16	710.2	24.9	748.1	20.8

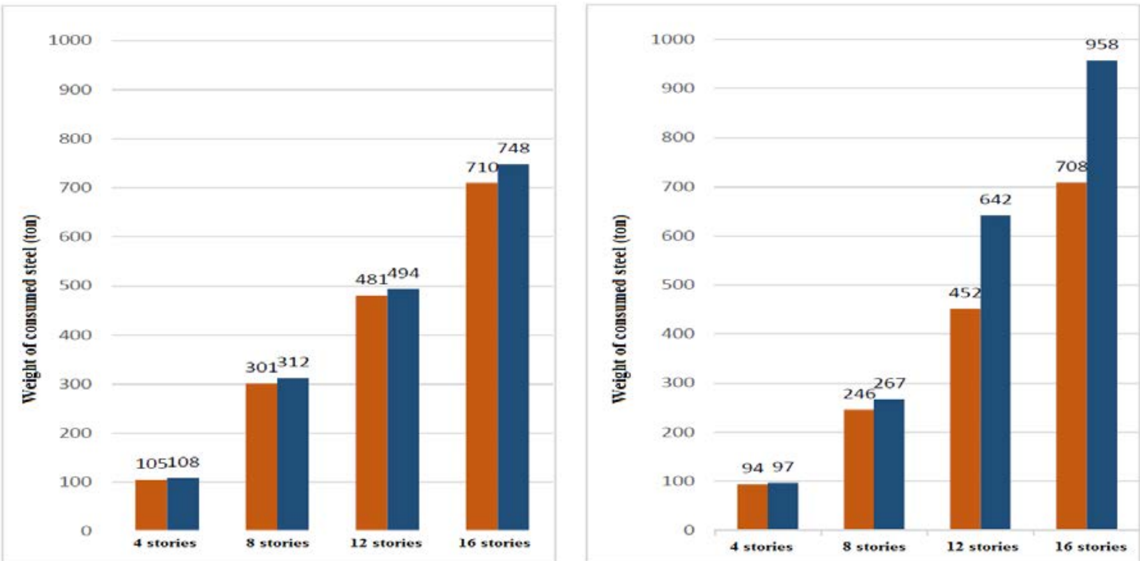

Figure 2: Interpretation of results

In addition, according to results of table 1, it can be inferred that in braced frames, drift of lower floors has small values and highest values occur in higher floors. For this reason, after controlling of regulation, it is observed that maximum displacement of roof in braced frames significantly decreases compared to moment frames.

This result can be seen in Figure 3. After presenting results of control of regulation on maximum roof displacement of system, results corresponding to comparison of two structural systems are provided. In table 2, values of maximum base shear for both structural systems are summarized.

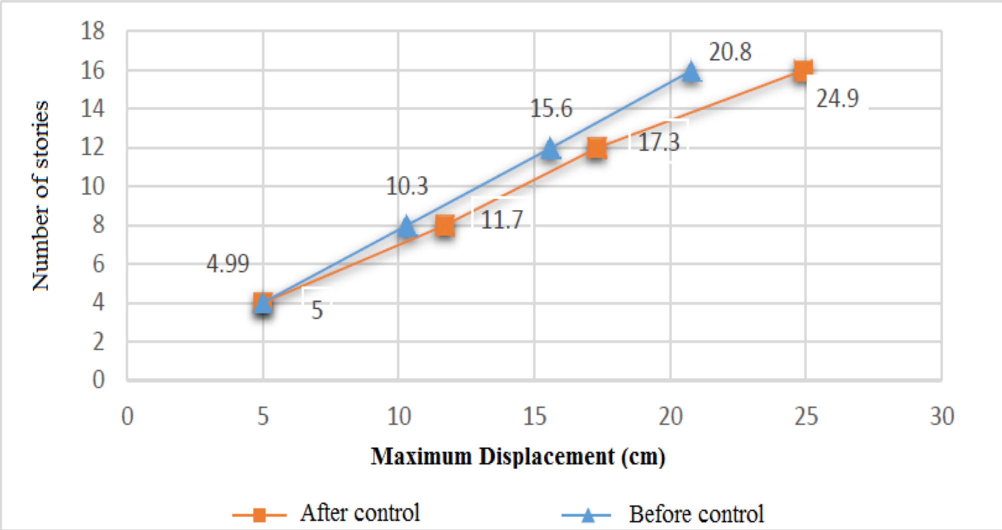

Figure 3: Maximum roof displacement in moment frames

Table 2: Values of maximum base shear

Stories	Braced frames	Moment frames
4	211.7	132.9
8	404.1	317.7
12	534.2	331.6
16	566.4	406.4

Table 3: Final weight of consumed steel

Lateral load bearing system	Stories	Columns (ton)	Beams (ton)	Braces (ton)	Overall weight (ton)
Braced frame	4	38.1	43.6	13.9	96.8
Braced frame	8	143.4	89.3	31.0	267.0
Braced frame	12	447.8	130.7	58.6	642.1
Braced frame	16	658.1	176.1	116.9	957.6
Moment frame	4	43.7	62.6	-	108.0
Moment frame	8	146.3	162.6	-	312.3
Moment frame	12	235.8	252.8	-	493.7
Moment frame	16	363.4	377.9	-	748.1

Results of table 2 illustrate that base shear forces corresponding to the braced frame are in average 147% of that of moment frames and in addition to application of more load to structure, it reveals that forces transferred to foundation of braced frames have larger values. Hence, in a similar case, braced frames require a stronger foundation. In table 3, final weight of consumed steel for each of the main elements as well as lateral load bearing system are presented. Results of table 3 show that as number of stories increases, steel consumed in braced frames will exceed that of moment frames. This matter is obvious in Figure 4.

In Figure 5 it can be observed that using braced frames in 4 and 8 stories buildings is more optimal compared to moment frames from economic point of view. However, in 12 and 16 stories buildings, due to significant contribution of regulation control to the weight of consumed steel, utilization of braced frames is more economical compared to moment frames.

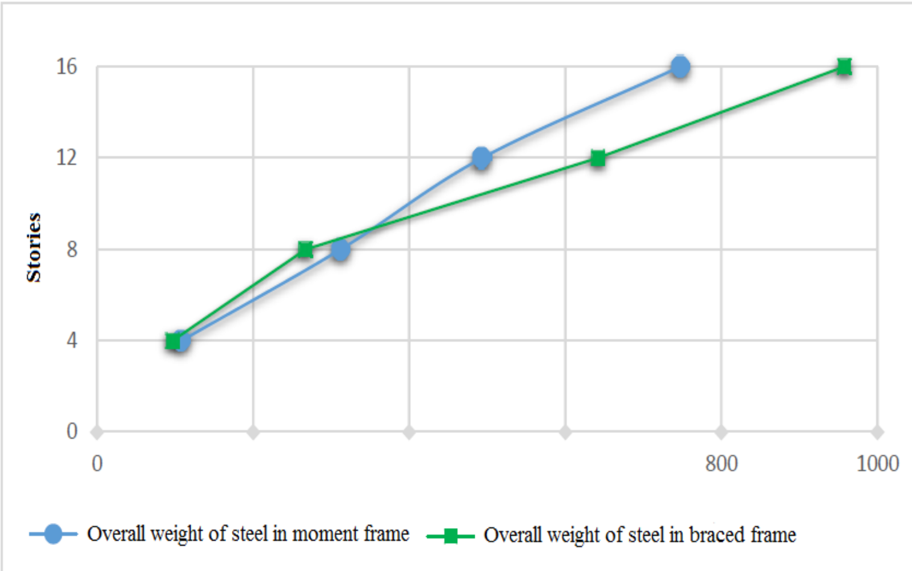

Figure 4: comparison of weight of consumed steel

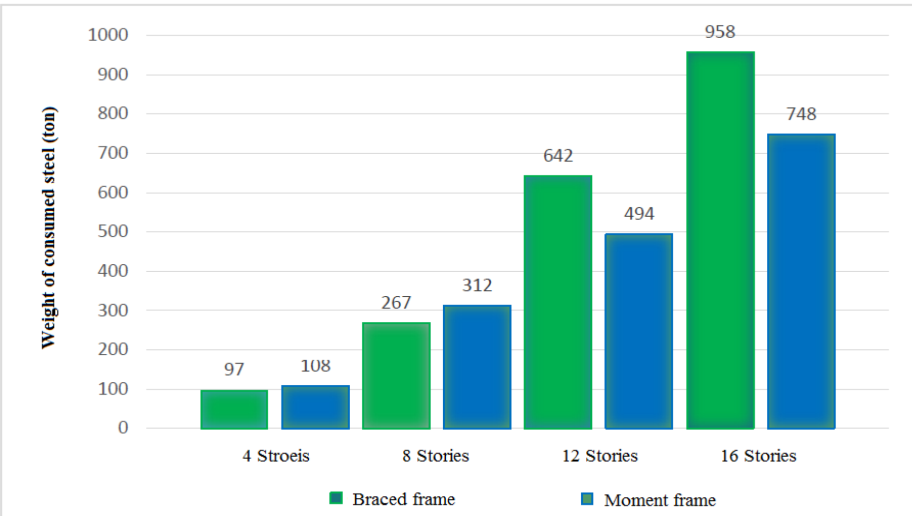

Figure 5: comparison of weight of consumed steel

4. Conclusion

In this paper, buildings with similar plans in 4, 8, 12 and 16 stories were modeled with difference structural systems and factors such as the effect of control of regulation for the weight of steel structure, maximum roof displacement, ultimate weight of the structure frame and values of base shear are explored and following results were obtained:

- In buildings with 4 and 8 stories, the average weight of consumed steel in braced frames is as much as 87% of that of moment frames. Hence, braced frames are more optimal.
- In buildings with more stories, consumed steel weight in moment frames is in average 77% of moment frames,therefore, utilization of moment frames is more economically justified.
- Maximum roof displacement in braced frame is in average 30% less than that of moment frames.
- Base shear force in moment frame is in average as much as 68% of that of braced frame and consequently, forces transferred to foundation in moment frames is less than braced frames.
- Control of regulations results in relative increase in the weight of building and as number of stories increases, this ratio increases as well. Such ratio is considerable for buildings with more stories specifically those having braced frames system so that for buildings with 12 and 16 stories with braced frames, 35% and 45% increase is observed in the weight of consumed steel, respectively and in buildings with moment frame, this increase is as much as 2.65% and 5.3%, respectively.

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